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NIST Response to the Fifth CORM Report on the Pressing Problems and Projected Needs in Optical Radiation Measurements

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Abstract

The Council for Optical Radiation Measurements (CORM) issues periodic reports which, in part, bear upon the mission and responsibility of the Radiometric Physics Division, Physics Laboratory. This report summarizes NIST's responses to the CORM Fifth Report issued in 1989 and is timed to be contemporary with the CORM Sixth Report to be issued in 1994.

Key Words: metrology, optical properties of materials, optical radiation, photometry, radiometry, spectroradiometry

Preface

The Council for Optical Radiation Measurements (CORM) had as a goal in its inception in 1972 to serve the interests of professionals and institutions engaged in optical radiation measurements. CORM is a non-profit organization and has among its aims and purposes the following:

> Assessment of national requirements for standards, calibrations, and interlaboratory collaborations.
>
> Establishment of national consensus of priorities for these requirements.
>
> Liaison with the National Institute of Standards and Technology (NIST) in order to advise NIST of requirements and priorities of the optical technology community.
>
> Dissemination of information on standards activities in optical radiometry and spectrophotometry.

To affect the core of its responsibility, CORM periodically surveys the optical radiation user community to elicit the perceived technical needs for measurements and standards. The results of the survey and prioritization are issued in the form of CORM reports. The most recent, the CORM Fifth Report, was issued in September of 1989. This report arranged the requests into two categories of optical measurement; radiometry and optical properties of materials. This follows the same division of technical categories started in the CORM Fourth Report. After study and consultation concerning the specific requests, the CORM report committee and the CORM Board of Directors established a priority need for the identified problems and formulated specific proposals for action.

The requests for action were not directed solely at NIST for fulfillment, but had components that involved industrial participation and university research and education. As the nation's primary standards organization, NIST has a leadership role and responsibility to establish new and better calibrations, standard reference materials, and special tests and thus to satisfy the central aspects of the problems identified in the CORM Fifth Report. This report summarizes NIST's attempts to respond to the problems outlined in the CORM Fifth Report relating to the nation's metrology needs in optical radiation measurement.

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I. GENERAL COMMENTS

The CORM Fifth Report has been widely circulated within the United States and to some extent in other parts of the industrialized world. As a consequence the efforts of CORM have not only benefitted program planning within NIST but have had an effect upon program planning and institutional direction in many parts of the world. The Fifth Report was assembled by surveying the CORM membership, categorizing the responses, and assigning a priority to the request or problem suggested by the response. The prioritization was established by a consensus of the CORM Board of Directors based upon draft proposals submitted by the Fifth Report Committee.

In the prioritization process, two categories were defined:

Priority 1: CORM feels that immediate action is necessary
Priority 2: These proposals are important but not as immediate as Priority 1.

Additional and perhaps less widespread requests and comments were placed in an appendix of the report. Requests were placed into two categories for consideration: radiometry and optical properties of materials. The categorization and prioritization allowed NIST to establish goals and objectives and apportion responsibility for action in an unambiguous fashion for those requests which were clearly a NIST responsibility. Some of the requests should best be addressed by other metrology institutions or from within the private sector of the optical manufacturing industry.

An additional benefit of the categorization and prioritization process has been its usefulness in obtaining the interest of other government agencies in participating in funding NIST activities. The CORM membership has representatives in other government agencies and many others act as suppliers of services and products to agencies such as NASA and the Department of Defense. It is useful for these agencies to have documented needs as an indication of where research and development funding is most gainfully employed to attend to national needs. In the ever expanding technical base in the United States, and in the consequent continually increasing demand for new and improved technical support from the national metrology laboratory, it would be impossible for NIST alone to respond to all the measurement needs identified by the technical community. By establishing a prioritized listing of needs, CORM thus helps other government agencies and private organizations identify their role and appropriate participation in optical radiation measurement service delivery.

As with other fundamental metrological areas, use of optical radiation measurement is diffused throughout the vast American technical enterprise. From the manufacture of scientific instruments and optical sensor systems for industrial process control to the paper on which the instruction manuals are written to describe their operation, optical radiation measurement is a key ingredient in the successful delivery of products. The huge American investment in space-based observation systems for weather, earth resource, agricultural monitoring, and national defense is critically dependent upon a reliable and accurate optical radiation measuring system for insuring the nation's technical accomplishments. NIST feels that CORM is a central participant in defining the measurement and support needs that this large and diverse community requires to enable American technology to remain in a world leadership position.

The demand on NIST for improved services spans all of the calibration and measurement support areas. These increased demands reflect an ever-growing, high technology manufacturing base in the United States being driven by international competitiveness to furnish high quality products. This is reflected in the move by American industry to adopt appropriate International Organization for Standardization 9000 series quality assurance program recommendations. The same motivation impels calibration and testing laboratories to obtain accreditation through a recognized accrediting organization. In order to assist American industry in this endeavor, NIST has expanded the National Voluntary Laboratory Accreditation Program (NVLAP) to include a calibration laboratory accreditation program. This will complement the existing programs in other parts of the world such as the National Measurement Accreditation Service (NAMAS) program in the United Kingdom. The NVLAP program to accredit testing laboratories has been expanded to include a wide variety of programs of physical, electrical, chemical, and optical testing areas. These efforts will greatly assist industrial access to high quality measurements, thus enabling them to subscribe more readily to the ISO 9000 series guidelines. The establishment of an enhanced NVLAP by NIST helps fulfill a suggestion made by Dr. Mielenz in his response to the CORM Fourth Report in which he suggested CORM work toward a goal of "Certification of Intermediate Calibration Laboratories".[1] To foster quality measurement services within NIST, a NIST Measurement Services Quality Committee has been established to oversee implementation of quality operations within the various divisions. The Radiometric Physics Division has begun implementation of ISO Guide 25 recommendations in all of its measurement services laboratories and expects to be compliant in 1994.

II. DISCUSSION OF CORM FIFTH REPORT PROPOSALS FOR ACTION

The CORM Fifth Report categorized the proposals for action into two areas: a) radiometry and b) optical properties of materials. There were eight proposals in the radiometry area; three were classified as priority one and five as priority two. The optical properties of materials had six proposals of which two were priority one and the remaining four were priority two. Not all of the proposals for action were directed at NIST for implementation; nevertheless, inasmuch as information is available, progress on satisfaction of the proposals will be discussed or suggestions for action will be made in this report.

a) Radiometry - Priority 1 proposals

R-1, Improved Standard of Spectral Radiance and Irradiance

A common element of CORM Reports dating from the Second Report in 1975 has been the expression of need for improved standards of spectral radiance and irradiance.[2] In the CORM Fifth Report this proposal generated the most interest and received the highest priority rating of all of the requests for action. For the most part NIST delivers calibrations and standards of spectral irradiance and radiance by the dissemination of calibrated lamps. These lamps are used by industrial and scientific customers to calibrate a wide range of instruments ranging from sophisticated earth observing satellite instruments to calibration of colorimeters and radiometers for production process control. The importance of the lamps to the technical and industrial programs is reflected in the intense interest in improving the availability and quality of lamps and their calibration.

The CORM Fifth Report specifically suggested the following;

a) Develop a practical lamp standard(s) of spectral radiance that is uniform and stable for 100 hours or more.

Wavelength range	Measurement Uncertainty (±3 sigma)
225.0 nm	± 1%
654.6 nm	± 0.3%
2400.0 nm	± 0.15%

b) Develop an improved lamp standard(s) of spectral irradiance that is stable for 100 hours or more.

Wavelength range	Measurement Uncertainty (± 3 sigma)
225.0 nm	± 1.1%
654.6 nm	± 0.5%
2400.0 nm	± 3.25%

NIST does not produce lamps for use in disseminating radiometric scales and must rely upon the traditional commercial source of lamps for use as calibrated artifacts. The circumstance is further aggravated in this particular instance as the major lamp manufacturers in the United States ceased production of standards quality lamps at approximately the time CORM formulated this request for improved standards. Regardless of the eventual resolution of the source of supply of lamps, the request implied a necessity for NIST to improve its spectral radiometric scales.

In cooperation with CORM subcommittee CR-1, NIST staff has labored to identify sources of standard quality lamps from manufacturers throughout the world. Although some foreign sources had been identified; the cost and supply problems at first seemed to discriminate against their widespread application in the United States. During the course of the CR-1 study, the availability of lamps from suppliers was continually changing, which frustrated efforts at a comprehensive solution to the supply problem. CR-1 issued its report in 1993 outlining the needs for radiometric and photometric sources.[3] One accomplishment of this effort has been the reemergence of a domestic supplier of FEL lamps suitable for spectral irradiance standards. As a result, NIST has recently resumed shipping spectral irradiance lamp standards and is seeking to gain acceptance for the use of the 1000 W FEL as a luminous intensity standard as well. This will be a significant step in solving the radiometric scale distribution problem.

To meet the improved and lower measurement uncertainty required for furnishing lamp standards of higher quality, NIST embarked upon a program to install a new and fundamentally more accurate radiometric base for all of its measurement scales. This was accomplished by the installation of a high accuracy cryogenic radiometer (HACR) which has the intrinsic uncertainty of 0.01% ($\pm$ 1 sigma) in measuring optical power. This device can then be used to improve detector responsivity scales, and with appropriate instrumentation, to place the spectral radiometric scales upon a chain of measurements starting with the HACR. This replaces the previous methodology of relying upon thermal sources and fixed-point blackbodies. Conversion has been accomplished for the photometric scales and shortly will be fully implemented for the spectral radiometric source scales.[4] Additional work has been undertaken to improve the quality of the variable-temperature blackbody source used for the calibration scale. These improvements will allow NIST to furnish calibrated sources at the uncertainty levels requested in the CORM Fifth Report. However, it is uncertain at this point whether the lamps supplied by commercial sources will have the stability and uniformity required. NIST encourages customers requiring the highest levels of accuracy to consider developing their own spectral radiometric scales based upon NIST-supplied absolute detectors.

R-2, Infrared Detector Standards

NIST obtained funding from the Department of Defense to start two new programs to address this need. The first, the Low Background Infrared (LBIR) facility, was constructed to calibrate low temperature blackbodies and detectors in a cold space environment. The facility will be described in a later section of this report. A second facility, the Infrared Detector Comparator (IRDC), operates at ambient laboratory temperatures and features a custom-designed, prism-grating monochromator that operates from 1.5 to 20 μm. The IRDC facility is operational and is being used to characterize newly developed transfer standard detectors in order to provide scales of detector responsivity in the infrared wavelength region. These transfer standard detectors are calibrated absolutely at laser wavelengths using the HACR.

NIST has an active program at both Gaithersburg and Boulder to develop superconducting materials for use in infrared detectors and to obtain more sensitive and useful devices. A new facility to characterize the reflectance in the infrared at cryogenic temperatures has been developed and will be essential to provide the characterization of absorptive materials for use in coating infrared bolometers. This is necessary to establish and verify the spectral responsivity of the detector. NIST expects these facilities to meet the critical needs expressed by this CORM proposal and will establish an hitherto unavailable capability for national scales of detector spectral responsivity. A high-sensitivity bolometer has been developed based upon commercially available devices and has been characterized for possible use as a transfer standard in the infrared region.[5,6]

R-3, Radiometry: Measurement Procedure and Technique

Progress on improvement in the area suggested by this proposal will require the participation of a wide range of U.S. institutions including NIST, universities, CORM, and scientific organizations. As a partial effort to help this endeavor, the Radiometric Physics Division has undertaken to update all of its SP-250 calibration services documents. The first round of documents will be completed during fiscal year 1994. NIST believes that joint programs between CORM and scientific organizations such as SPIE can be very beneficial for educational impact. Noteworthy in this regard is the joint workshop CORM held with SPIE concerning imaging radiometry. CORM also participated in the joint symposium on infrared calibrations held at Utah State University in 1992. NIST staff, including those from the new Flat Panel Display Facility in the Electronics and Electrical Engineering Laboratory (EEEL), gave a short course at the SID conference in 1993. They discussed fundamental colorimetry and its application to visual displays of various kinds. NIST sees a continual and important role for

CORM to foster educational activities which are designed to improve the level of competence of radiometric and spectrophotometric calibration activity in the United States.

b) Radiometry - Priority 2 proposals

R-4, Imaging Radiometry

NIST obtained funding from the Department of Defense to establish a program in infrared imaging technology. The applications are to calibrate and characterize various wide-aperture blackbody sources used in DOD calibration activities of infrared imaging systems. NIST has developed stable and well-characterized, ambient-background, wide-aperture sources (10 cm diameter) for use as a uniform target for imaging-system gray-scale calibration. The source serves to calibrate individual pixels for responsivity. The Radiometric Physics Division is developing, in conjunction with EEEL at NIST, a program to improve metrology for visual display devices and color imaging systems. NIST agrees that there is opportunity for growth in this area as ever more sophisticated array detector systems become available. Their application in spectral radiometry and photometry will be one of the interesting challenges of the next several years.

R-5, Long Wave Infrared (LWIR) Radiometry (3-50 μm)

NIST obtained funding from the Department of Defense to establish the LBIR calibration facility.[7,8,9] This facility is now operational and provides calibration of blackbody sources for radiation temperature from 100 K to 500 K. A new cryogenic monochromator has been designed and will serve to spectrally characterize blackbody sources and sensitive low-background infrared detectors. These characterizations are carried out in the cryogenic chamber of the LBIR facility which can operate at 20 K for sustained times. The primary radiometric tool of the facility is a sensitive (10 nW) absolute cryogenic radiometer.[10,11] This instrument can characterize sources and detectors with better than 1% uncertainty ($\pm$ 2 sigma) in this wavelength region. NIST has an active program to update the facility and to develop appropriate transfer standard detectors for use by industry. This proposal and its companion R-2, suggest an increased demand for infrared calibration services, a fact noted in surveys of direct customer contact with NIST.

R-6, Photometry: Improved Measurement Capability

NIST has completely rebuilt the photometric calibration facility in the Radiometric Physics Division. Additionally the fundamental photometric unit, the candela, has been placed upon a detector basis.[4,12] The detector basis is directly related to the HACR through silicon transfer standards calibrated on the detector response calibration facility. The photometric test bench has been completely rebuilt using modular optical tables and commercial optical components. A high-resolution linear transducer provides a direct length input to the computer operated data system for specifying the distance measurements needed in photometric calculations. In addition to offering luminous intensity calibrations based upon the HACR, NIST now provides illuminance and luminance calibrations employing the new system. As lamps become available (see section on R-1), NIST will resume the shipping of standard lamps for luminous intensity and flux. The uncertainty in the measurement is a factor of 3 improvement over the previous photometric installation at NIST.

A new, senior photometrist, Dr. Yoshi Ohno, has been added to the staff of the Radiometric Physics Division to oversee the calibration and research effort in photometry. Under Dr. Ohno's direction, a new program to place the luminous flux scale on the absolute detector base has been undertaken by the Division. This will complete the unification of photometric measurements under the auspices of the high accuracy afforded by the HACR incorporation into NIST radiometric activities.

R-7, Pulsed Radiometry

The Radiometric Physics Division is involved with the aircraft industries and the FAA to improve radiometry for flashing aircraft lights. Past efforts to obtain funding in pulsed radiometry have been unsuccessful. NIST-Boulder is heavily involved with high frequency applications appropriate for fiber optics communications. The frequency and wavelength demands for fiber optic's purpose is different from the demands of the fast pulse light sources that was a concern of the CORM proposal. A variety of requirements for measurement still remain unfulfilled in this area and the expertise of a metrology laboratory such as NIST is essential to their eventual solution. NIST will continue to have this measurement requirement on the table for consideration for both internal and external support.

R-8, Laser Beam Profile

There are numerous commercial products that purport to accommodate this interest and as a consequence NIST has not actively ventured into this area.

c) **Optical Properties of Materials/Priority 1 proposals**

O-1, SRM Set for Visible and Near-infrared Spectral Reflectance Factor Measurements

Two diffuser SRMs are still available, namely: #2015 (Opal glass) and #2021 (Black porcelain enamel). The other diffuser SRMs for ultraviolet to near-infrared spectral reflectance factor are now out of stock. Efforts being made to meet the needs include intrinsic standard development, instrument development, and candidate material selections. An intrinsic standard has been developed for 6°/hemispherical reflectance factor.[13] Similar efforts are being pursued for 45°/0° reflectance factor with pressed polytetrafluoroethylene powder.[14,15] A new monochromator-based instrument with high throughput and ease of operation has been designed and constructed. A collaborative agreement has been made with Labsphere, Inc. to characterize and select candidate materials for 6°/hemispherical reflectance factor SRMs in the 250 nm to 2500 nm spectral region.

Currently, NIST provides calibration service for 6°/hemispherical reflectance factor from 250 nm to 2500 nm and for 45°/0° reflectance factor from 380 nm to 770 nm. NIST also provides SRM #1920 reflection wavelength standard for visible to near-infrared spectral region.

O-2, SRM for Infrared Total Hemispherical Reflectance Factor

NIST obtained funding from the Department of Defense to establish the IR (2 μm - 20 μm) absolute directional-hemispherical reflectance factor measurement facility as well as to develop an IR diffuser standard. The facility, which is expected to be completed at the end of FY94, includes two different integrating devices: a hemi-ellipsoidal collecting mirror and an integrating sphere. The hemi-ellipsoidal collecting mirror which has been designed and constructed, incorporates non-imaging optical technology to significantly improve the measurement accuracy over previously considered designs.[16] It will be used with both Fourier transform and grating-monochromator-based spectrophotometers. The integrating sphere device has been designed and constructed, and consists of a sphere, dewar, detector, and non-imaging optics to improve spherical response uniformity.[17,18]

Candidate materials for consideration as diffuse reflectance SRMs have been examined. Scattering measurements of these samples performed at 10.6 μm wavelength demonstrated that a gold-coated, plasma-sprayed aluminum sample had the best diffuse scattering characteristics.[19] It is expected that at the end of next fiscal year NIST will be able to provide the SRMs and other measurement services required by industry.

Two other related projects are: IR wavelength standard and Fourier transform infrared (FTIR) spectrometer calibration. Recently, a polystyrene SRM has been developed for calibration of the wavelength scale of FTIR instruments from 2.9 μm to 20 μm. This material, which will be issued as SRM #1921 in FY94, provides thirteen reference wavelengths. A comprehensive project to calibrate FT-IR spectrometers is in progress.[20] Several error sources are being investigated: detector non-linearity, detector non-equivalence, inter-reflection, and beam deviation.

d) Optical Properties of Materials/Priority 2 proposals

O-3, SRM for Visible and Near-infrared Bi-directional Reflectance Distribution Functions (BRDF)

NIST obtained funding from the Department of Defense and NASA to establish bidirectional scattering facilities which include laser-based and monochromator-based instruments.[21] The laser-based BRDF instrumentation has been designed, constructed, and characterized, and is now being assessed for uncertainty.[22,23] This instrument with wide dynamic range, high angular accuracy, raster scanning capability, and low background scattering will be used to study the optical scattering properties of highly polished surfaces. Radiometric Physics Division staff members participated in developing ASTM BRDF measurement method.[24] Prototype specular-type SRMs have been produced using a technique of rough grinding and partial polishing to obtain reproducible BRDF levels.[25] The cleaning and storage techniques will be investigated as part of the effort for SRM development.

A monochromator-based BRDF instrument has been designed and constructed. The new instrument has raster scanning capability, high throughput, and will permit measurement from 200 nm to 2500 nm.

O-4, SRM for Visible High Transmission Density

A general method has been developed using laser heterodyne detection to measure high optical densities.[26] This method can be used for any wavelength range where lasers and appropriate optics are available and allows measurement that is insensitive to background radiation-a convenience of particular importance for infrared measurements. In addition to direct determination of optical density, the technique is useful for assessing out-of-band rejection in the transmission wings of filters. This method does not directly depend upon an artifact from NIST and hence can be independently established by laboratories for their own purpose and, to some degree, be considered an intrinsic standard.

Recently, a direct method relying on detector linearity was used to measure a set of filters with optical densities (O.D.) from 0 to 5 at 10.2 μm and 10.6 μm, and these filters were found to have sufficient neutral character to be promising as candidate SRMs for calibration of the linearity of an FT-IR spectrometer.[27]

O-5, Precise Documentary Standardization of Geometric Conditions in Color Spectrophotometry

Radiometric Physics Division staff members are participating in developing a CIE technical draft report TC2-14 on "measurement of reflectance and transmittance." They are also involved in working with CORM Committee OP-1 on Geometry, and in developing ASTM standard practice on measurement of translucent materials. It is expected these efforts will improve the documentary standards defining measurement procedures for this area.

As a related effort, the effects of temperature scale changes on CIE standards for colorimetry have been documented in a NIST publication.[28]

O-6, SRM Set for Whiteness

NIST has developed a set of SRMs (#1931) for corrected fluorescence spectra. The measurement geometry was 60°/30°.[29,30] SRM #1931 consists of five standards: four fluorescent-colored standards and one sintered PTFE sample. NIST has a reference spectrofluorimeter which can be used at 45°/0° or any other geometries. The whiteness standard can be developed jointly by industry and NIST if urgent needs arise and funding is available.

III. CONCLUSIONS

The CORM Fifth Report has served as an impetus for significant improvement and change in NIST programs serving the optical radiation measurement community. The time and energy invested by the members of CORM in preparing studies such as the Fifth Report provide an excellent venue to establish industrial needs recognized within the programs of NIST and other government agencies. This information is useful for the manufacturers of optical instruments and equipment as a guide in establishing specifications for products they provide and to develop new products and service.

At NIST a major and long-lasting result of the Fifth Report will be the efforts put into establishing a much improved and more accurate radiometric measurement service. This is underpinned by the HACR and its derived influence on the spectral radiometric measurement scales. This will be a permanent and significant contribution to improving the quality efforts in optical radiation measurements in the United States. Additionally, the Radiometric Physics Division is upgrading the UV-VIS-IR diffuse reflectance instrumentation, and developing BRDF and IR diffuse reflectance instruments. The IR wavelength SRM is completed and three types of SRMs are in the developing stage: UV-VIS-NIR and IR diffuse reflectance, and BRDF.

Since the CORM Fifth Report was issued in 1989, NIST has undergone changes in its mission which, among other things, includes the new Advanced Technology Program (ATP). In addition to this program which offers direct support to industry for development of new technologies, NIST staff are encouraged to enter into Cooperative Research and Development Agreements (CRADAs) with appropriate industrial groups in which there is a joint interest in a particular development area. In this manner, American industry can avail themselves of expertise and facilities which exist at NIST and elsewhere in the federal establishment in order to develop products for commercial purpose. The optical-based industry is well represented in the ATP awards and in the establishment of CRADAs. The Radiometric Physics Division currently has five CRADAs with optical manufacturing companies.

NIST envisions a continued and perhaps increased involvement in assisting U.S. industry expand its worldwide markets and pursue the manufacture of quality products. The NVLAP effort is being expanded to accommodate requirements for registration and certification of testing and calibration laboratories. In areas of standard development or policy determination requiring joint CORM/NIST effort, CORM needs to identify its members that can sign cooperative agreements with NIST to accomplish the desired goals. It will be a challenge for NIST and CORM to broaden its representation to encompass measurement needs in emerging technologies and to expand CORM's membership to provide input to NIST on the needs for new technology.

NIST looks forward to the CORM Sixth Report and its attendant recommendations.

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